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# Two Methods of Bathymetry-Sidescan Sonar Data Comparison for Improved Determination of Sonar Towfish Position

*Anna Crawford*

**Defence R&D Canada**

Technical Memorandum

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Anna M. Crawford

**Defence R&D Canada – Atlantic**

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DRDC Atlantic TM 2002-110
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# Abstract

Two methods are presented that use existing local bathymetric data to determine the position of the sidescan sonar towfish during surveys. In the absence of direct measurements of towfish position as survey work is underway, later determination of this position by other means is necessary to obtain accurately geo-referenced seabed imagery from the sonar data. The methods investigated rely on either large objects in the sonar field of view or the profile of the total water depth along the towfish survey track. Results of the analysis are compared with independent estimates derived from ship geometry and logbook cable length entries and from short-baseline acoustic tracking system measurements of the range to the towfish. In the several examples shown, both methods found layback solutions within a few metres of the independent estimates.



# Résumé

On présente deux méthodes utilisant des données bathymétriques locales existantes pour déterminer la position du sonar à balayage latéral remorqué durant les relevés. En l'absence de mesures directes de la position de la remorque durant les relevés, la position doit être déterminée plus tard par d'autres moyens afin d'obtenir des images du fond marin géoréférencées exactes à partir des données du sonar. Les méthodes étudiées sont fondées sur la présence de grands objets dans le champ du sonar ou sur le profil de la profondeur d'eau totale le long de la trajectoire de relevé de la remorque. Les résultats de l'analyse sont comparés à des estimations indépendantes dérivées de la géométrie du navire et des entrées sur la longueur du câble dans le journal de bord, ainsi que sur des mesures de la distance de la remorque obtenues à l'aide d'un système de poursuite acoustique à courte ligne de base. Dans les nombreux exemples, les solutions données pour la distance navire-remorque dans les deux méthodes se situaient à quelques mètres près des estimations indépendantes.

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# Executive summary


**Introduction**

The largest problem in producing accurately geo-referenced seabed images from sidescan sonar survey data is determining the position of the sonar towfish during the survey. Two methods have been developed to solve this problem using available bathymetric data covering the same area as the sonar survey.

**Principal Results**

The first method uses large objects in the sidescan sonar field of view that are resolved in the lower resolution bathymetry data. The example shown uses the locations of a group of car bodies seen in both data sets. The spatial offsets (East and North) between the two sets of locations, corresponding to the offsets between the ship and towfish as the survey was underway, are found based on minimizing the partial Hausdorff distance between them. The second method discussed uses the water depth measured by the towfish along its track. The solution for the along and acrosstrack offsets gives the maximum correlation between a cross-section through the bathymetry along a course at those offsets from the ship track and the towfish-measured water depth profile. This method is illustrated with examples with both straight and curved survey tracks, as well as with a case where the cable length varied over the length of a survey leg.

The results, in the form of acrosstrack offset and layback, are compared with independent estimates derived from ship geometry and logbook cable length entries and, where available, with measurements of the range to the towfish by a short-baseline acoustic tracking system. The comparison is favourable (within a few metres) in the cases where the cable length was fixed over a survey leg and promising in the case where it was changing.

**Significance of the Results**

The methods presented here offer a means for improving the accuracy of geo-referenced sidescan sonar imagery. As long as there are suitable bathymetric features for the analysis, these techniques could be applied in the absence of the usual sources of layback information (for example, logbook cable length entries or a survey line run in the reverse direction over the same target). The algorithms used are straightforward.

**Future Plans**

The very simple towfish ship-following model that was used in this implementation of the algorithms limits the accuracy of the results, particularly on curved survey tracks. As well, there has been no attempt at optimizing the computations. These improvements would increase accuracy in the more difficult situations (curved tracks, changing cable length) and make the methods more practical for larger data sets.



Crawford, A. M. 2002. Two Methods of Bathymetry-Sidescan Sonar Data Comparison for Improved Determination of Sonar Towfish Position. TM 2002-110. DRDC Atlantic.

# Sommaire


**Introduction**
Le problème le plus important dans la production d'images du fond marin géoréférencées exactes à partir de données de relevé obtenues avec un sonar à balayage latéral consiste à déterminer la position du sonar remorqué durant le relevé. Pour résoudre ce problème, on a élaboré deux méthodes utilisant des données bathymétriques disponibles qui couvrent la même zone que le relevé sonar.

**Principaux résultats**
La première méthode utilise de grands objets situés dans le champ du sonar à balayage latéral qui sont résolus dans les données bathymétriques de plus basse résolution. Dans l'exemple, les emplacements d'un groupement de carrosseries présent dans les deux ensembles de données sont utilisés. Les décalages spatiaux (est et nord) entre les deux ensembles d'emplacements, qui correspondent aux décalages entre le navire et la remorque durant le relevé, sont établis en minimisant la distance de Hausdorff partielle qui les sépare. La deuxième méthode mentionnée utilise la profondeur de l'eau mesurée par la remorque le long de son trajet. La solution relative au décalage longitudinal et au décalage transversal donne la corrélation maximale entre une section transversale bathymétrique le long du trajet entre ces décalages de la trajectoire du navire et le profil de profondeur de l'eau mesuré par le sonar remorqué. Cette méthode est illustrée à l'aide d'exemples comprenant des trajectoires de relevé en ligne droite et sinueux, ainsi que par des cas où la longueur du câble variait sur la distance de l'étape du relevé.

Les résultats, présentés sous forme de décalage transversal et de distance navire-remorque, sont comparés à des estimations indépendantes dérivées de la géométrie du navire et des entrées sur la longueur du câble dans le journal de bord et, le cas échéant, de mesures de la distance entre le sonar remorqué obtenues à l'aide d'un système de poursuite acoustique à courte ligne de base. La comparaison est favorable (différence de quelques mètres) dans les cas où la longueur du câble était fixe durant l'étape du relevé et prometteuse lorsque celle-ci variait.

**Signification des résultats**
Les méthodes présentées ci-dessus constituent un moyen d'améliorer l'exactitude des images géoréférencées obtenues à l'aide d'un sonar à balayage latéral. Lorsqu'il existe des caractéristiques bathymétriques convenables pour l'analyse, ces techniques peuvent être appliquées en l'absence des sources habituelles de données sur la distance navire-remorque (par exemple, entrées sur la longueur du câble dans le journal de bord ou le tirage de la ligne de relevé dans le sens inverse au-dessus du même objectif). Les algorithmes utilisés sont simples.

**Plans futurs**
Ce modèle très simple de suivi de navire-remorque qui a été utilisé dans la présente implantation des algorithmes limite l'exactitude des résultats, particulièrement si les trajectoires de relevé comprennent des courbes. Également, aucune tentative d'optimisation des calculs n'a été faite. Ces améliorations accroîtraient l'exactitude dans des situations plus complexes (trajectoires avec courbes, variation de la longueur du câble) et rendraient ces méthodes plus pratiques pour de plus grands ensembles de données.



Crawford, A. M. 2002. Two Methods of Bathymetry-Sidescan Sonar Data Comparison for Improved Determination of Sonar Towfish Position. TM 2002-110. RDDC Atlantique.

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# Acknowledgements

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# Introduction

The motivation behind most sidescan sonar surveys leads to the requirement that the resulting seabed imagery be geo-referenced in order to locate features in the images in a real-world coordinate system. In the case that the sensor is mounted on a towfish, this can be difficult since as a rule, towfish position is less well known than the position of the ship that is towing it. Even if the length of tow cable is known, hydrodynamic forces and other effects lead to cable curvature and complicated following behaviour of the towfish behind the ship. This potentially limits the positioning accuracy of the geo-referenced seabed images resulting from post-processing of the sonar data, and as well, introduces registration noise into images compiled from overlapping survey swaths. At the same time, bathymetric sonars are generally ship-mounted, and therefore bathymetric survey data can have inherently better positioning accuracy.

The work presented here suggests solutions to the towfish positioning problem using existing geo-referenced bathymetry data to determine the position of the survey track that was followed by the towfish. The techniques rely on the presence of suitably unambiguous bathymetric features along the towfish track such as shoals or outcroppings or objects in the sidescan sonar survey swaths that are large enough to be resolved by the lower-resolution bathymetric sonar. Examples will be presented illustrating the methods that have been developed and the results of the analysis will be compared with independent estimates.

## Statement of the Problem

In order to properly geo-reference sidescan sonar data from a towfish-mounted sonar, the positions of the towfish at the times that samples were recorded must be determined. Though towfish attitude, depth and altitude are measured, generally its absolute position is not. Towfish position is usually determined from the ship position, which is defined in this case as the position of the onboard GPS receiver, ship geometry and the layback. There are both along and acrosstrack offsets between the GPS receiver, the towpoint and the towfish which must be accounted for. All positions are projected onto a horizontal plane (the water surface).

In this case, a very simple towfish following model has been used to determine towfish position from ship position. It is assumed that the towfish follows behind the towpoint on a straight cable with the ship's instantaneous heading, determined from the course (course made good) rather than from the measured gyro heading. The towfish is positioned on a line extending back from the centreline of the ship with this determined heading and with layback calculated from the length of cable, the elevation of the towpoint and the instantaneous towfish depth. The heading of the towfish is assumed to be the same as that of the ship (again, course made good). In reality, there is almost always some degree of cable curvature due to hydrodynamic forces, and as well, the towfish heading will certainly not match the ship heading through turns. Acrosstrack positioning errors can arise when the ship track crosses currents, or if there is some source of asymmetric drag on the towfish or cable. Errors in geo-referencing of the processed sidescan sonar images result from deviation of the towfish from this assumed track due to any of these factors, or measurement errors, such as in the towpoint offsets or cable length.

The relevant side and plan view geometries of the ship and towfish are illustrated in Figure 1, with the along and acrosstrack directions defined as parallel and perpendicular to the ship heading (course made good) with positive forward and to starboard. The GPS receiver is shown in an arbitrary location with offsets in two directions to the towpoint. Figure 1 also illustrates potential towfish positioning errors. The modeled position of the towfish is outlined with solid lines, and possible unpredicted positions with dashed lines. In the side view, cable curvature reduces the real layback between the ship and towfish. In the plan view, current crossing the ship track results in acrosstrack error in predicted towfish position and a difference between the ship course made good and gyro heading.

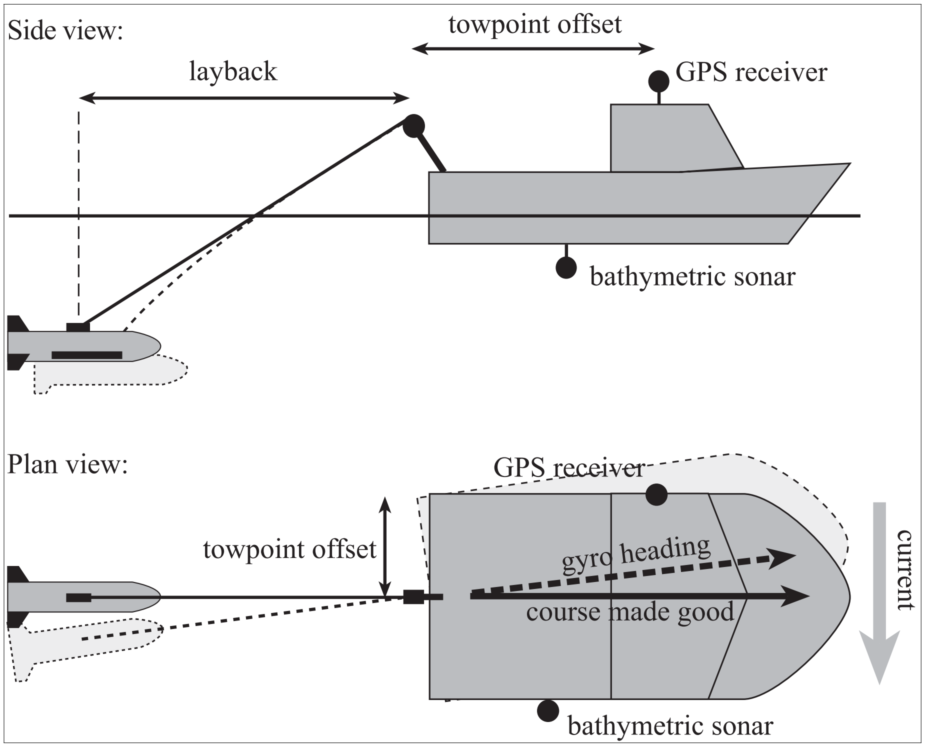


**Figure 1**: Side and plan views of modeled towfish and ship positions.

# Two Approaches to Solutions

Two methods of solving the towfish positioning problem using available bathymetry data have been developed. These will be described in subsequent sections, following summaries of the requirements and assumptions involved.

## Requirements

The primary requirement is a set of bathymetric survey data covering the same area as the sidescan sonar survey. The spatial resolution of the bathymetry data will almost certainly be lower than that of the sidescan sonar data, but needs only to resolve bathymetric features along the towfish track or large objects in the sidescan imagery. The second method to be presented also requires measurement of the depth of the towfish to determine the total water depth along the towfish survey track (towfish altitude, if not recorded directly, can be derived from the sidescan sonar data).

## Assumptions

Several assumptions must be defined. The ship position, generally measured using a Global Positioning System receiver and processor in differential mode (DGPS), is assumed to be accurate, as is the geo-referencing of the bathymetry data, through whatever processing method has been applied. It is assumed that the largest difference between the positions of the towfish and ship is the layback (see Figure 1). Here, the way that the towfish follows the ship is modeled in a very simplified manner, as described in the previous section. In the model, there is no cable curvature in the horizontal or vertical planes, and further, the off-stern angle to the towfish from the towpoint is zero (i.e. that the towfish is located on the extension of the ship centreline). It is assumed that this will introduce only small errors to the geo-referencing of the sidescan imagery, particularly along straight survey tracks.

## Two Methods

Two methods have been developed that use bathymetric information to improve determination of towfish position. The first, referred to as *object matching*, uses distinct objects in the sonar field of view that are large enough to be resolved by the bathymetric sonar. The second method, referred to as *bathymetry matching*, uses comparison of the water depth at the towfish (altitude plus depth below the water surface) and the bathymetric data. Both methods will be described in the following sections.

The results of the analysis are presented in the form of determined offsets between the positions of the towfish and ship during the surveys - the shifts in position required to align the sidescan images with the bathymetric data. These can be compared to independent estimates derived from the ship geometry, logbook cable length entries and the simple towfish following model and in one case, to measurements of range to the towfish.

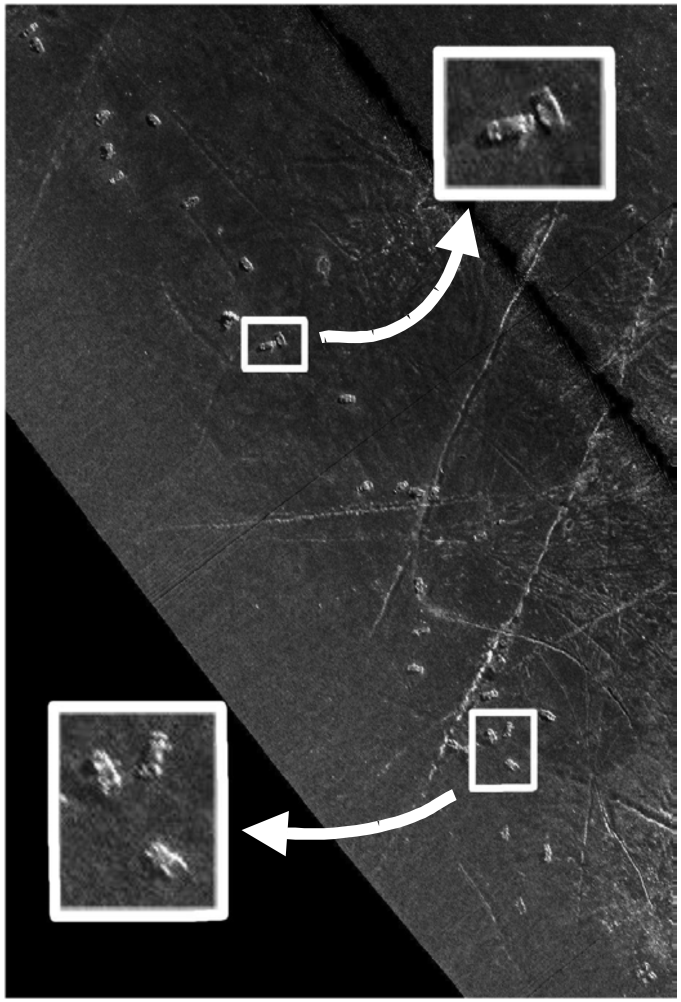

**Figure 2**: Sidescan sonar image of car bodies on the seabed in Bedford Basin (north is upward).

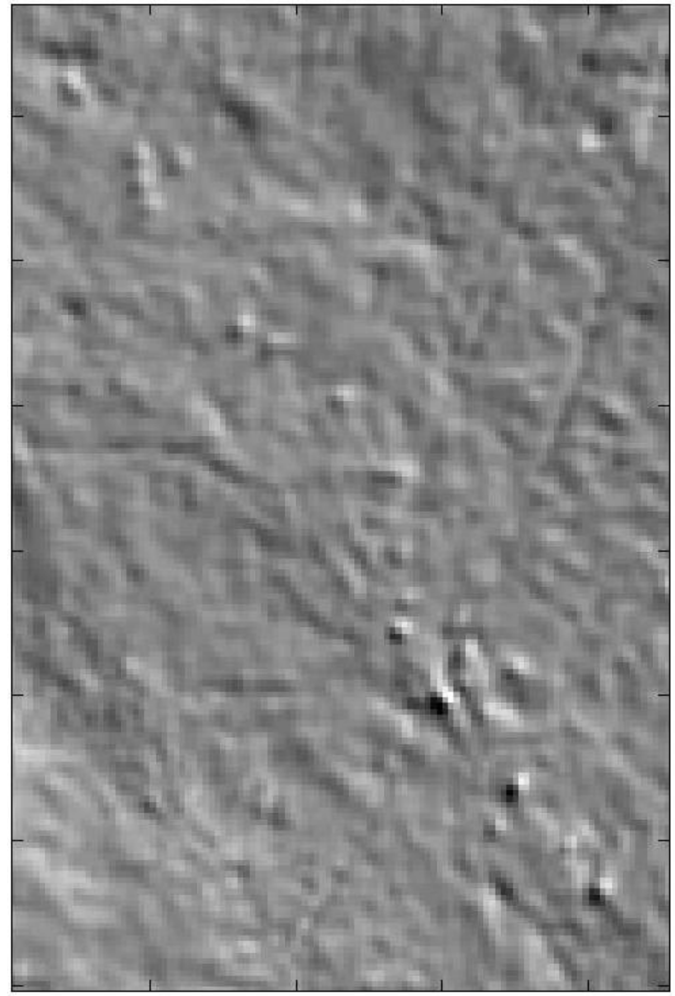

**Figure 3**: Filtered bathymetry data from the same area as shown in Figure 2.

# Method 1: Object matching

The discussion to follow will be illustrated by an example from a sidescan sonar survey of an area in Bedford Basin, Nova Scotia, where there are a collection of car bodies (Volvos) distributed roughly along a NW-SE line. There is corresponding bathymetric survey data of the Basin at 2 m (horizontal) resolution.

Figure 2 shows a processed sidescan sonar image that includes some of the car bodies. The two insets are magnified portions of the image showing detail of several of the cars. North is up in the image and the pixel resolution is approximately 20 cm by 20 cm. The path followed by the towfish is seen as the dark diagonal stripe, the nadir coverage gap, crossing the upper right corner of the image. Several anchor drag marks can also be seen in the image.

Figure 3 shows filtered bathymetric data from the same area. A 3-pixel by 3-pixel 45º directional filter has been applied. This transforms slopes facing the North-East direction, toward the upper right corner in the image, to positive intensities (white being the steepest) and those facing away to negative intensities (steepest are black). This transformation is intended to approximate the effect of the direction and angle of incidence of seabed sound illumination by the sidescan sonar. Comparing with the sidescan sonar image in Figure 2, the highlights on the car bodies are on the sides facing the towfish track. The coarser horizontal resolution of the bathymetry data (2 m) is obvious and makes objects appear much less clear than in the corresponding sidescan image.

In post-processing, the sidescan sonar image was geo-referenced to a point on the ship centreline, labelled "A" in Figure 4. The offset between objects in the resulting image and the corresponding locations in a real-world coordinate system, as determined by matching with the bathymetry data, should approximately equal the horizontal offset between the towfish position during the survey, labelled "B" in Figure 4, and this point on the ship. Part of this offset is the alongtrack distance between the ship position and the towpoint (assumed to be well determined by the ship geometry) and the remainder is the layback (see also Figure 1). This can be expressed as either Easting and Northing offsets, or knowing the ship heading, an alongtrack offset. In the most general case, there is acrosstrack offset as well (not shown in Figure 4), perpendicular to the alongtrack offset.

The locations of the car bodies visible in both images were digitized (using the "ginput" mouse digitization function of Matlab) and are shown in Figure 5. The axes units are in meters (Eastings and Northings) relative to an arbitrarily chosen point roughly in the middle of the survey area. There is an obvious shift between the two sets of points in a roughly NW-SE direction, the direction of the ship track, which is consistent with the difference in position of the ship and towfish (A and B in Figure 4). There are fewer target locations in the set of points from the bathymetry data, since some closely located targets which can be seen in the sidescan image are not separated in the bathymetry image, and some are not resolved at all.

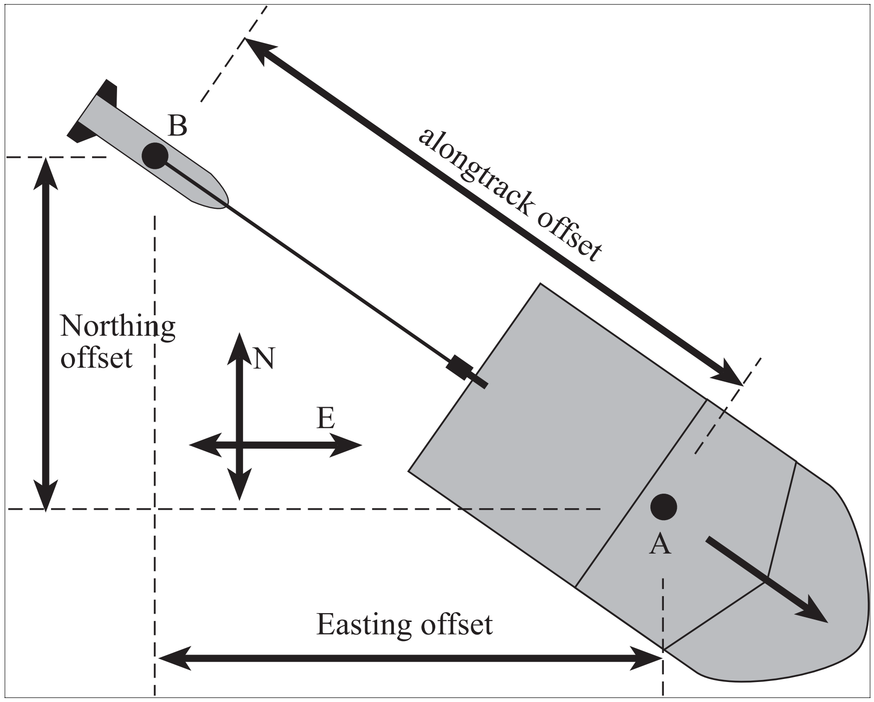


**Figure 4**: Offsets between ship position (A) and towfish position (B), which are determined by comparison with bathymetric data.

The method for determining the offset between the two sets of car positions is based on the partial Hausdorff distance, *D(A,B)*, between two sets of points *A* and *B*, defined as

$$D(A,B) = \underset{a \in A}{k^{th}} \left( \min_{b \in B} d(a,b) \right)$$

where $a$ is a member of $A$, $b$ is a member of $B$, and $k^{th}$(...) refers to the $k^{th}$ quantile value of the set of values in parentheses. In this particular application, the distances $d(a,b)$ are the Euclidian distances from points in $A$ to points in $B$, taking the 75% quantile. This method is more robust to outliers than the classical definition of the Hausdorff distance, which takes the 100% quantile (largest value). The Hausdorff distance is well-known in fields such as pattern recognition and machine vision (Huttenlocher et al, 1993; Olson, 1998). An advantage of this approach is that it is not required that the two sets contain the same number of points. The calculation proceeds by stepping through a range of values of angular and spatial (x and y, or East and North) offsets, applying these offsets to the set of less well positioned points (those from the sidescan image) and finding the offset values for which the partial Hausdorff distance between the two sets of points is minimized. This method would not be suitable for large point sets, but in this case where they are most likely to be limited in number, the computational cost is not a concern. For the case illustrated here, where the larger set has 31 points, there was a slight gain in computation time using a coarse search, followed by a finer search to improve the solution.

The best fitting solutions for the East and North offsets that align the two sets of car positions in this case are -35 m East and 48 m North, with a 0° angular offset. The resulting positions are also shown in Figure 5 (green triangles). In terms of along and acrosstrack offsets, these are -60 m alongtrack, aft of the ship, and -3 m to port (ship heading was approximately 141°). The GPS processor used during this trial had a latency of 0.9 s, so with the ship speed of about 6 knots or 3 m/s, an additional -3 m of alongtrack offset compensates for the distance travelled during the GPS latency period, therefore the total alongtrack offset is -63 m.

A logbook entry made during the survey reports the tow cable length was 57 m. The sonar data files show the average towfish depth was about 33 m below the surface along this track. The geometry of the ship has offsets between the GPS antenna and the towpoint of about -19 m alongtrack, with the towpoint about 6 m above the water surface. Working through the geometry in the alongtrack direction (see Figure 1), these values give an alongtrack offset between the GPS receiver and the towfish of -61 m (neglecting cable curvature), which compares very well with the present results. The solution for the acrosstrack offset perhaps gives an estimate of accuracy: zero to within 3 m.

The solution for the offsets has been determined in an East-North coordinate system so as to be generally suitable for any two sets of points. The solution could easily be constrained by limiting the search set using other available information such as the ship heading (the towfish necessarily follows the ship). The East-North coordinate system also limits this particular implementation to sidescan sonar survey data collected along straight tracks, since turns change the relative North and East components of the along and acrosstrack offsets.

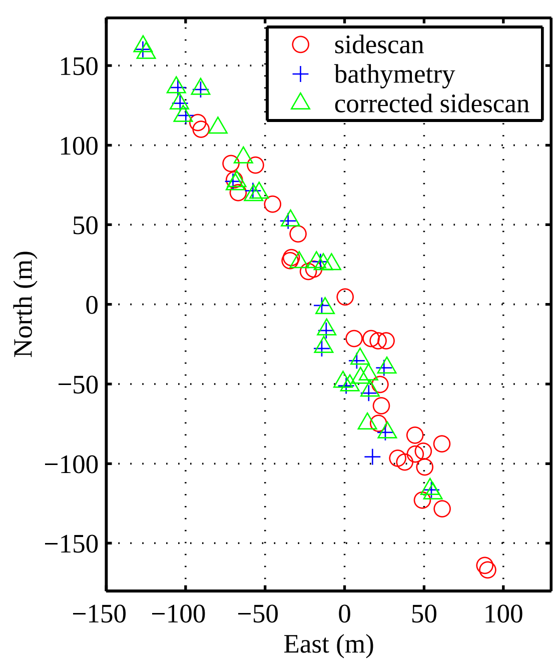


**Figure 5**: Positions of the car bodies in the sidescan and bathymetry images and results of the point matching algorithm.

This method relies on there being suitably scaled objects in the sidescan sonar data that are then resolved in the bathymetry data. In this case, with 2 m resolution bathymetry data, the car bodies are only just resolved, and then only by filtering the data appropriately. Geological features would be suitable if key locations can be identified in both data sets, for example, points along a shoal. As implemented here, this method also requires that the horizontal offset between the ship and towfish is constant. In order to find solutions in the case that this changes through a survey due to variation in towfish depth (operating in a terrain following mode, for example), the problem can be set up to solve for the length of cable rather than the horizontal component.

## Method 2: Bathymetry matching

In the second method, local bathymetry data is compared to the total water depth measured by the sidescan sonar towfish along its track (altitude plus distance below the water surface) with interpolated cross-sections from the bathymetry data set. Figure 6 illustrates the bathymetry used in the first example. This data is from the same survey as shown in the previous section, but includes several more of the one-minute sonar data files in the survey line beyond that shown in Figure 2. Recalling the filtered bathymetry data shown in Figure 3, that area is located in the North-West corner of the area shown in Figure 6. The cars are not discernable in the unfiltered data plotted with this vertical scale, and are very difficult to detect even with an expanded vertical scale. Some sort of filtering, such as the slope transformation, is necessary to identify these objects.

The ship track (black line) is also shown in Figure 6 overlaying the bathymetry. This is shown again in Figure 7. Note that in this figure, the x-axes of the plots show the Easting coordinate only, relative to an arbitrary location nearby, and that the ship track was roughly in the NW-SE direction. Figure 7 compares a cross-section interpolated from the 2 m by 2 m

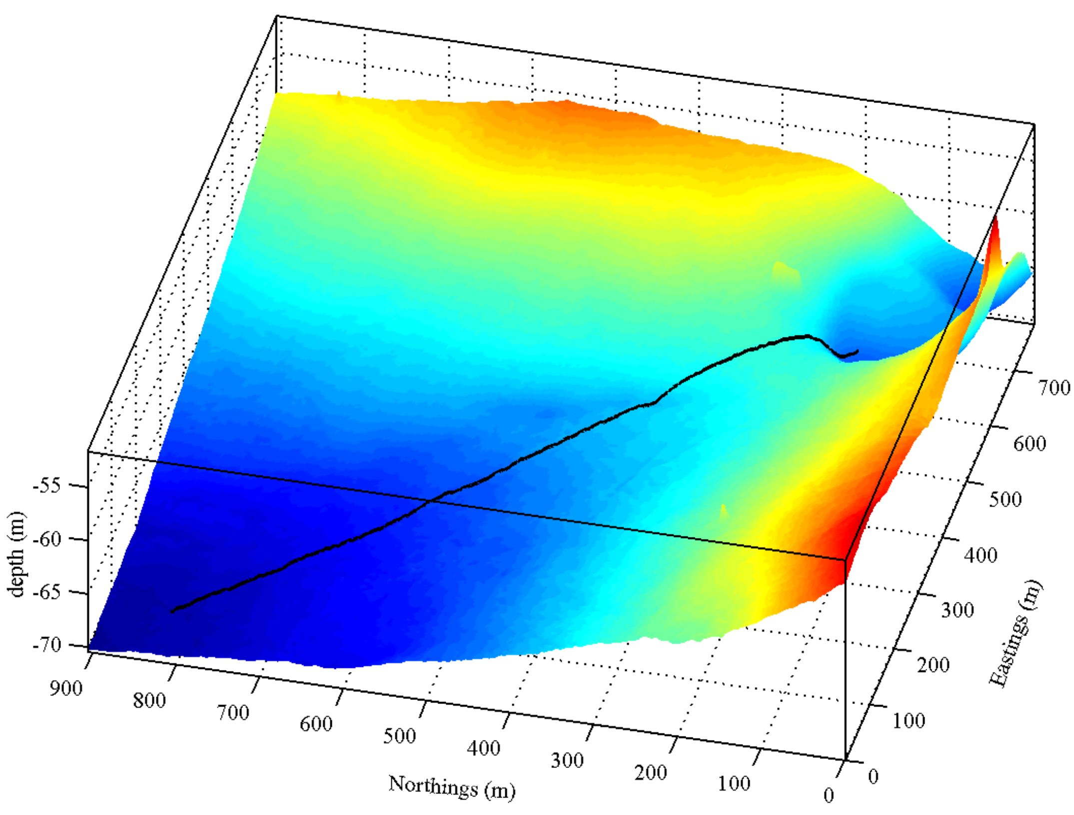


**Figure 6**: Perspective view of the bathymetry along the ship track shown in Figure 5 and in the surrounding area.

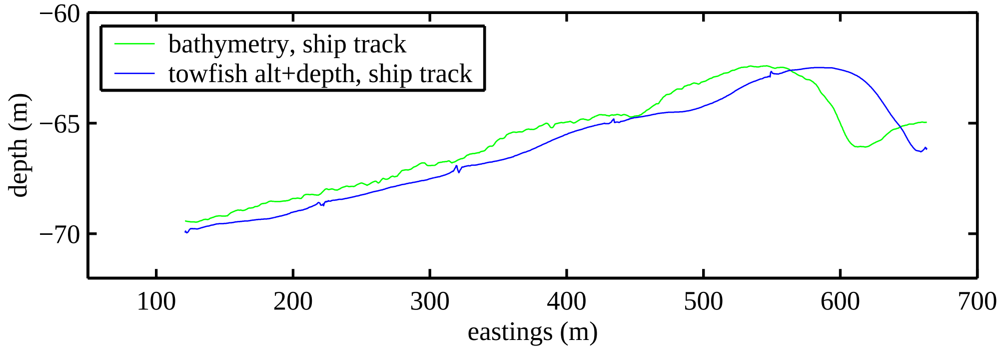


**Figure 7**: Towfish-measured water depth and bathymetry interpolated along the ship track from the bathymetry data set shown in Figure 6.

bathymetry data along the ship track (green line) and the total water depth measured by the towfish also plotted as a function of the ship's Easting position (blue line). The offset to the right of the blue line relative to the green line indicates the offset in Easting position between the ship and the towfish during the survey.

The method for determining this offset is based on maximizing the match between the shape of the alongtrack water depth measured by the towfish and the shape of interpolated cross-sections through the bathymetry data set over a series of calculated tracks at a range of along and acrosstrack offsets from the ship track. The "goodness" of the match is measured by the normalized cross-correlation coefficient between the measured and interpolated bathymetry profiles. Figure 8 shows the towfish-measured water depth plotted against the Easting coordinate of the determined towfish track (blue line) along with the interpolated bathymetry cross-section along that track (red line). The Easting component of the total offset which has been determined is also shown for comparison with the offset between the profiles seen in the upper plot.

In this case, the ship position is referenced to the position of the GPS receiver, as illustrated schematically in Figure 1 - i.e. there are both along and acrosstrack offsets between the ship position and the towpoint. The optimal offsets determined by this method are -63 m alongtrack and 6 m acrosstrack (to starboard) from the GPS receiver position to the towfish. These results are very similar to those of the previous analysis, which as measured from the

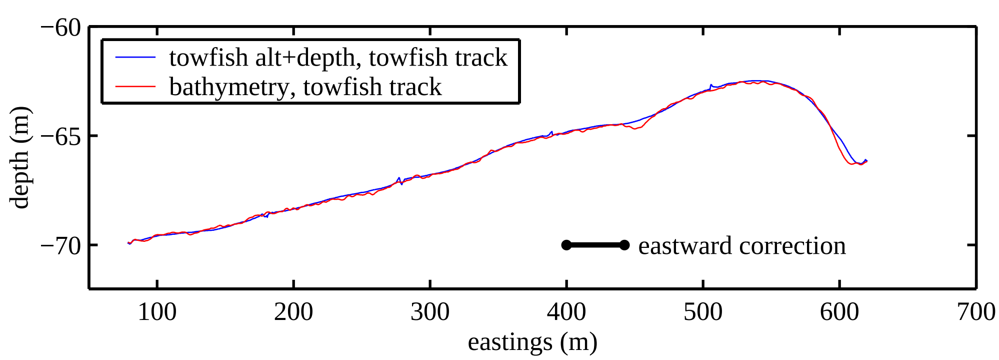


**Figure 8**: Towfish-measured water depth and bathymetry interpolated along the ship and towfish tracks from a local bathymetry data set.

GPS receiver are -63 m alongtrack, and 2 m to starboard (5 m minus 3 m). Note that unlike the previous method, the latency of the GPS processor does not affect the present results as they depend on the relative offset between two sets of positions which are on the same time base (ship position and towfish position determined from that ship position), independent of the absolute time.

There are some constraints on suitable bathymetric geometry for this technique. Obviously there must be some distinguishing feature in the bathymetry to correlate against. The perspective view of the bathymetry surrounding the ship track shown in Figure 6 indicates that in this case the placement of the ship track on the background bathymetry is unambiguous. It is not difficult to imagine cases where this is not so.

As implemented, this method is limited to surveys at fixed towfish depth and cable length, as is the previous method. By solving this problem in an along-acrosstrack coordinate system however, curved survey tracks are not a limitation, except for the shortcomings of the over-simplified towfish following model. Figures 9 and 10 illustrate application of this method to an extreme example of curved survey tracks (also in Bedford Basin). In Figure 10, note that the x-axis shows distance along the survey track, rather than the Easting component as before. The largest mismatches between the towfish-measured water depth and the bathymetry data set are during the sharpest parts of the turns and during changes in towfish depth, as would be expected given the very rudimentary straight-cable following model.

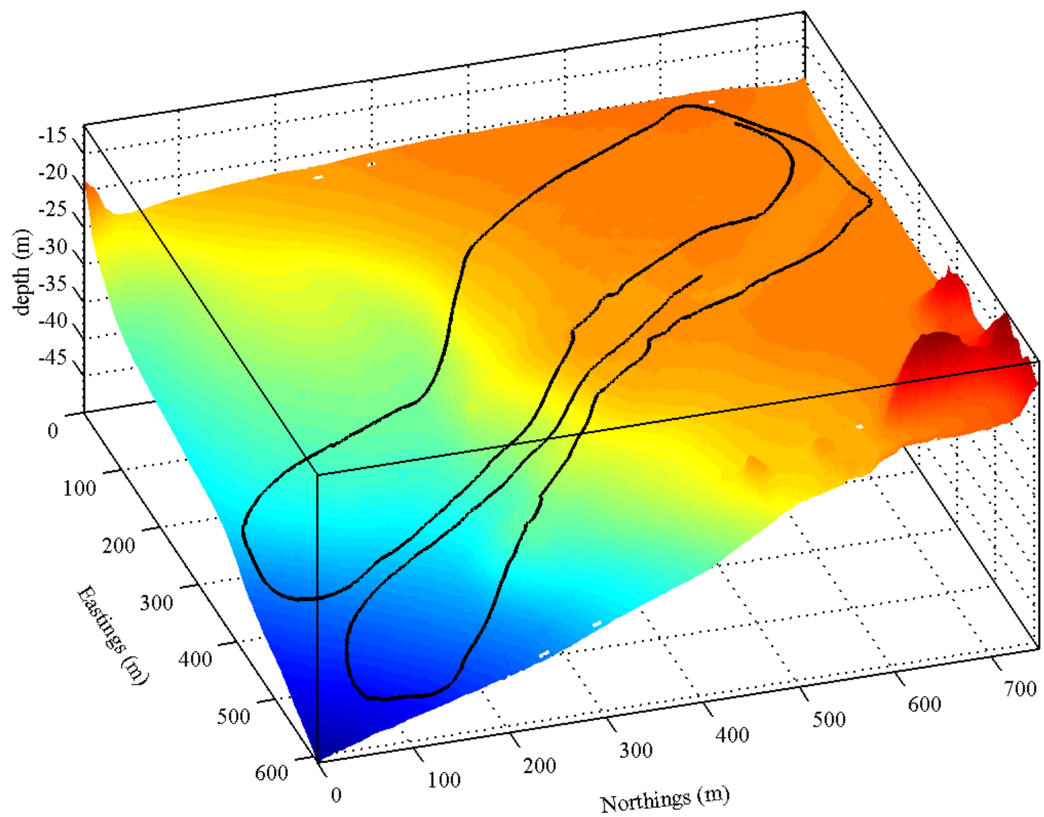


**Figure 9**: Perspective view of bathymetry around a curved survey track.

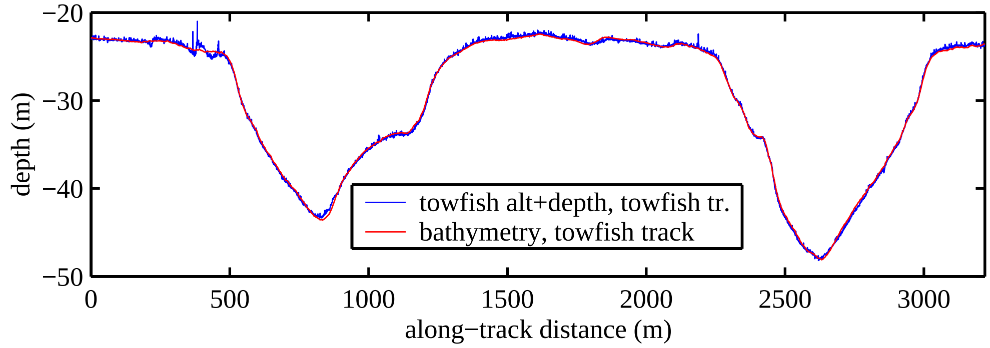


**Figure 10**: Measured water depth and interpolated bathymetry along a survey track through turns.

In this case, the solutions for the offsets are -23 m alongtrack and -2 m to port (again, both measured from the GPS receiver). A smaller vessel was used during this survey, with the along and acrosstrack offsets from the GPS receiver to the towpoint being about -6.5 m and -1.5 m to port respectively (the GPS receiver was to the other side of the towpoint than on the other vessel). The towpoint was about 0.5 m above the water surface. A logbook entry made during this survey indicates that the cable length was 20 m and the mean recorded towfish depth below the water surface was 8.5 m. Working through the geometry as before (including the calculated 2 m portside offset of the towfish from the GPS receiver), the alongtrack offset is -24.5 m. Again, this compares quite well with the offset determined by matching the bathymetry.

A third and final example illustrates a case where the length of cable was changing over the duration of a single straight survey leg (towfish depth was also changing). The water depth profile along the track has been broken into shorter overlapping segments and alongtrack offsets have been determined for each of these segments by a method similar to that just described. Figure 10 illustrates the series of offset solutions along a west-to-east survey line in St Margarets Bay, Nova Scotia, along with measurements obtained using a short-baseline acoustic tracking system (ORE Trackpoint II) and estimates derived from logbook cable length entries (all as functions of ship position).

The solutions for alongtrack offset were calculated for segments 200 m in length (shown by the labelled bar in the upper plot, Figure 10), with 50% overlap. The across-track offset was set at a fixed value of 5 m, determined by the ship geometry. As before, the "goodness" of the fit was assessed using the normalized cross-correlation coefficient between the towfish-measured water depth and interpolated bathymetry cross-sections. There are gaps in the series of offset solutions near the 1200 m and 3000 m marks since, in the first case, the maximum correlation found was lower than 0.75 and in the second, a solution could not be found by the algorithm (the maximum correlation was at one of the search range endpoints). These solutions are compared with two other sets of measurements. 1) The short-baseline tracking system measures range and bearing from a receiver to a transponder located on the towfish and these have been converted to alongtrack offset for comparison using the towfish depth and ship geometry. 2) The logbook entries of cable length have been matched to the ship position by time and converted to alongtrack offsets using the simple straight-cable towfish following model (finding the projection onto the water surface of the length of cable

extending behind and below the ship, as in Figure 1). Keep in mind that log entries are made only when there are changes in cable length. The alongtrack offset seems to be overpredicted by calculation from the log entries, particularly for longer cable lengths. The comparison between the alongtrack offset solutions by the bathymetry matching method and the measurements by the Trackpoint system is quite good.

The lower plot in Figure 10 shows the interpolated bathymetry and towfish-measured water depth along the ship track and illustrates a subtlety of bathymetry data. The overall mean depth will vary between sets of bathymetry survey data depending on the tide or which datum water depths are made relative to, so there is a small vertical offset between the two sets of bathymetry measurements shown. In the previous plots (Figures 7, 8 and 10), the small mean vertical offset was removed. An advantage of using a correlation calculation for measuring the quality of the match is that it is insensitive to this, where other methods may not be.

There are several comments to be made about the alongtrack offset solutions in this last example. In this case, the length of the segments (200 m) was chosen to maximize the alongtrack resolution of the solutions and still have reasonable correlation coefficient values (only 2 points failed). Very short segments may not contain enough information to determine a solution, and the definition of "short" depends on the character of the local bathymetry - bland bathymetry will require longer segments for solutions to be found (if they can be at all). Strong correlation also does not necessarily indicate a correct match: for example, two flat

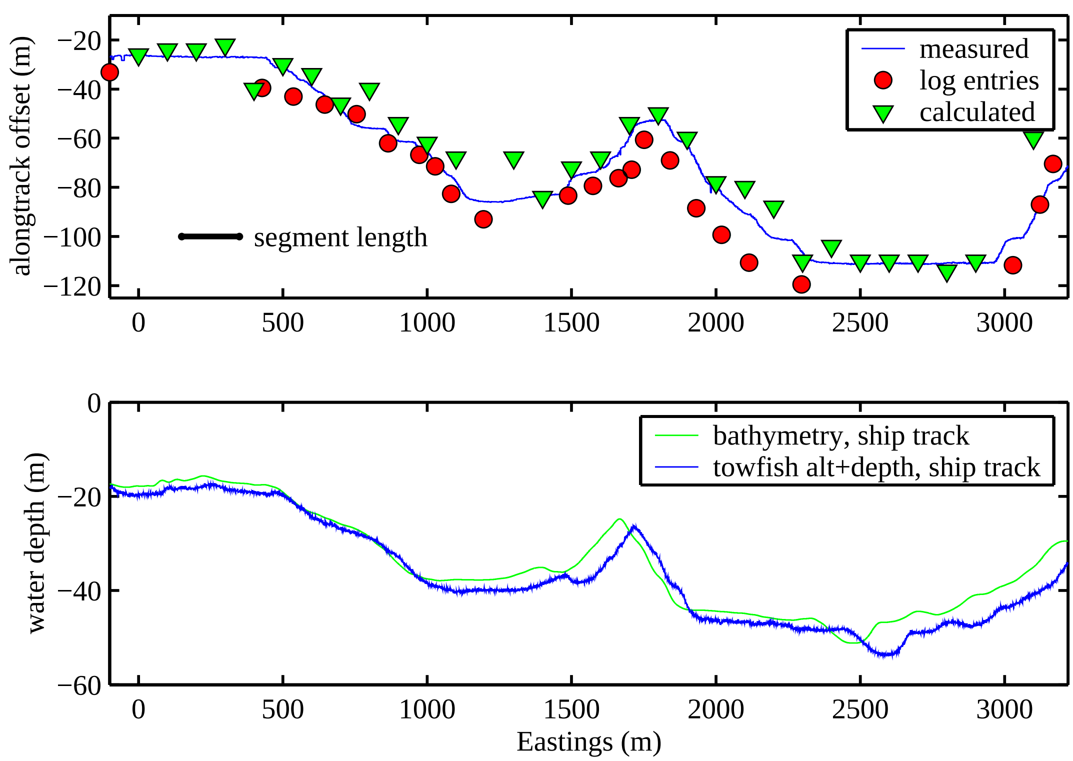


**Figure 11**: Calculated alongtrack offsets along a segmented track, compared with measurements and estimates derived from logbook entries.

profiles will give high correlations for meaningless offset values. The requirement for the length of the segments given the perhaps locally variable character of the bathymetry has not yet been quantified. Figure 10 shows that as expected, the match between the measured (Trackpoint) and calculated offset is best in areas where there are bathymetric features of suitable scale, for example, in the area around the "hill" at 1700 m along the track. Finally, the overprediction of the alongtrack offset by the cable length calculation again indicates that a better towfish following model needs to be used, or at least that the logbook entries should be a last resort.

# Notes on Implementation

Both methods presented here have been coded as Mathworks Matlab© script files that have simple algorithms and execute relatively quickly, despite no attempt being made at optimization. The test cases contained only small amounts of data, so any larger scale implementation would require improvements in efficiency of the coding, particularly where searching through the values of offsets by looping through the same calculation many times. As well, the very simple towfish following model that has been used here will not be suitable in situations where the cable length is any longer than in the cases shown here.

These methods have been developed as post-processing tools. The object matching method requires that the sidescan sonar data is first processed into an incorrectly geo-referenced image, implying then that two passes of this processing are required to obtain a properly geo-referenced image. The bathymetry matching method only requires the total water depth (towfish altitude and depth records) from the sidescan sonar data files, which can be extracted easily prior to processing the sonar data into images.

# Conclusions

Two methods for determining the relative offset between the ship and the sidescan sonar towfish have been developed based on comparison between sidescan sonar data and local bathymetry. The first method compares a set of locations of features in the sonar images with corresponding locations in the bathymetry data. The second method compares the measured water depth along the towfish track with cross-sections through the bathymetry data. The results of the analysis, in terms of along and acrosstrack offsets, compare favourably with independent estimates of the offsets derived from logbook cable length entries and ship geometry, and from measurements of range to the towfish by a short-baseline locating system.

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Two methods are presented that use existing local bathymetric data to determine the position of the sidescan sonar towfish during surveys. In the absence of direct measurements of towfish position as survey work is underway, later determination of this position by other means is necessary to obtain accurately geo-referenced seabed imagery from the sonar data. The methods investigated rely on either large objects in the sonar field of view or the profile of the total water depth along the towfish survey track. Results of the analysis are compared with independent estimates derived from ship geometry and logbook cable length entries and from short-baseline acoustic tracking system measurements of the range to the towfish. In the several examples shown, both methods found layback solutions within a few metres of the independent estimates.

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